

Fuel Cells

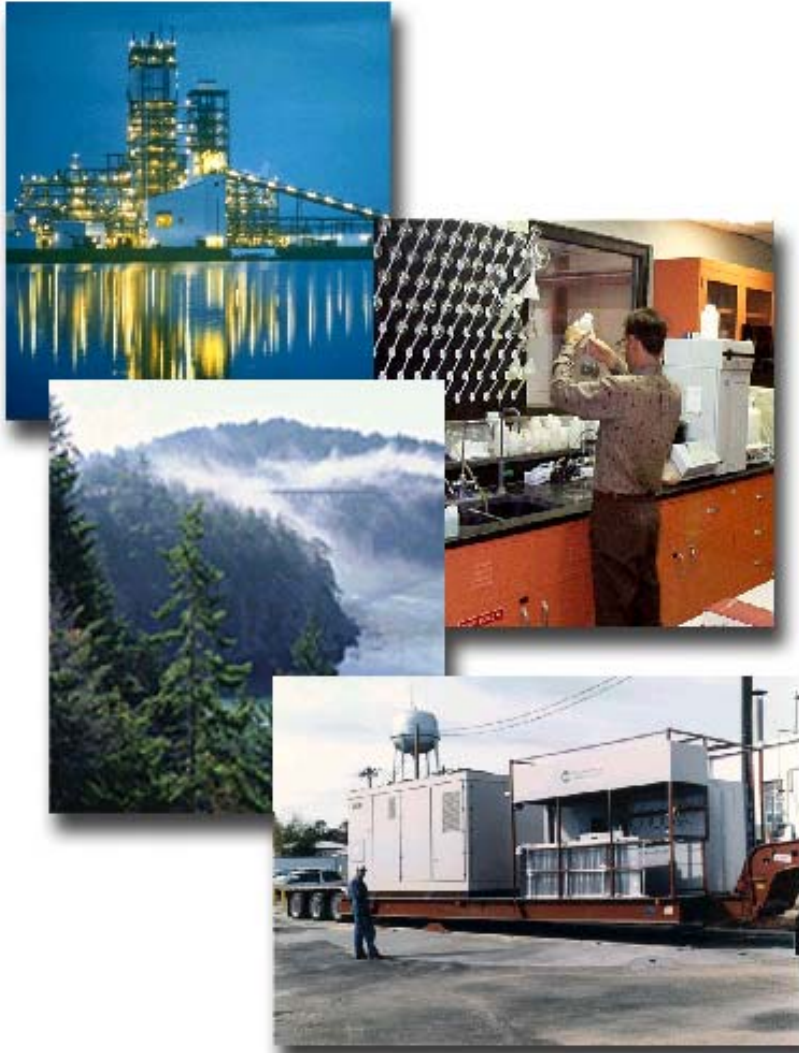


**Dr. Mark C. Williams,
NETL, U.S. Department of Energy**

Strategic Center for Natural Gas



National Energy Technology Laboratory (NETL)



What We Are

- One of US DOE's 15 National Laboratories
- Government Owned and Operated

What We Do

- Shape, fund, and manage DOE Stationary Fuel Cell Program
- U.S. largest funder of Fuel Cells
- Conduct analyses to support DG policy

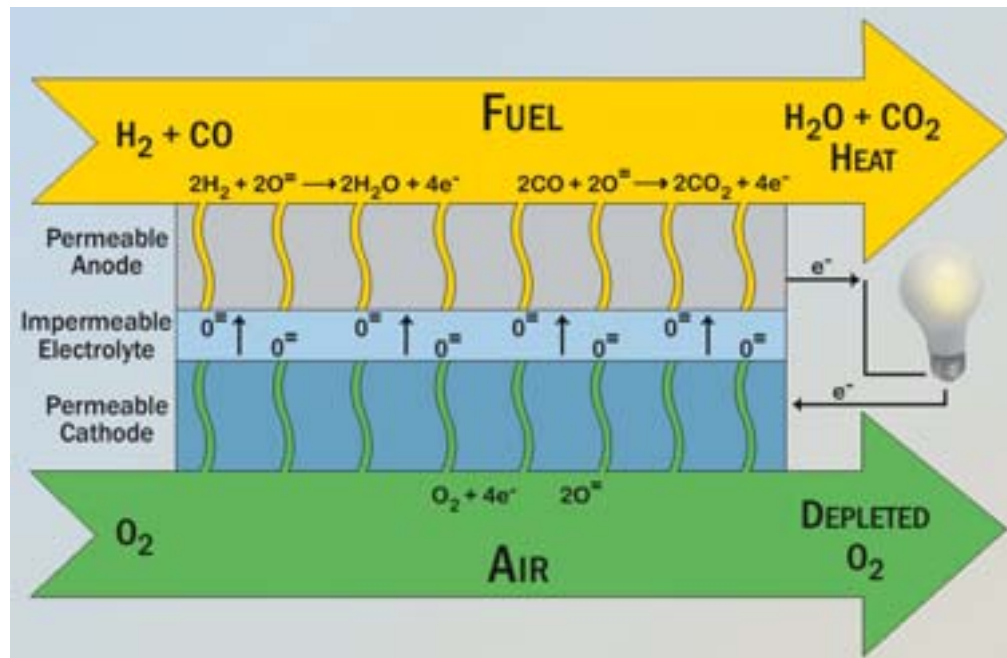


US DOE Fuel Cell & Related Federal Budgets (FY 2002)

<i>DOE FE Stationary Fuel Cells</i>	<i>\$58.7</i>
<i>Transportation Fuel Cells</i>	<i>\$41.9</i>
<i>Cogeneration/Fuel Cells</i>	<i>\$ 5.5</i>
<i>Hydrogen Research & Development</i>	<i>\$31.5</i>
<i>DOD (CERL, NAVY)</i>	<i>\$14.6</i>



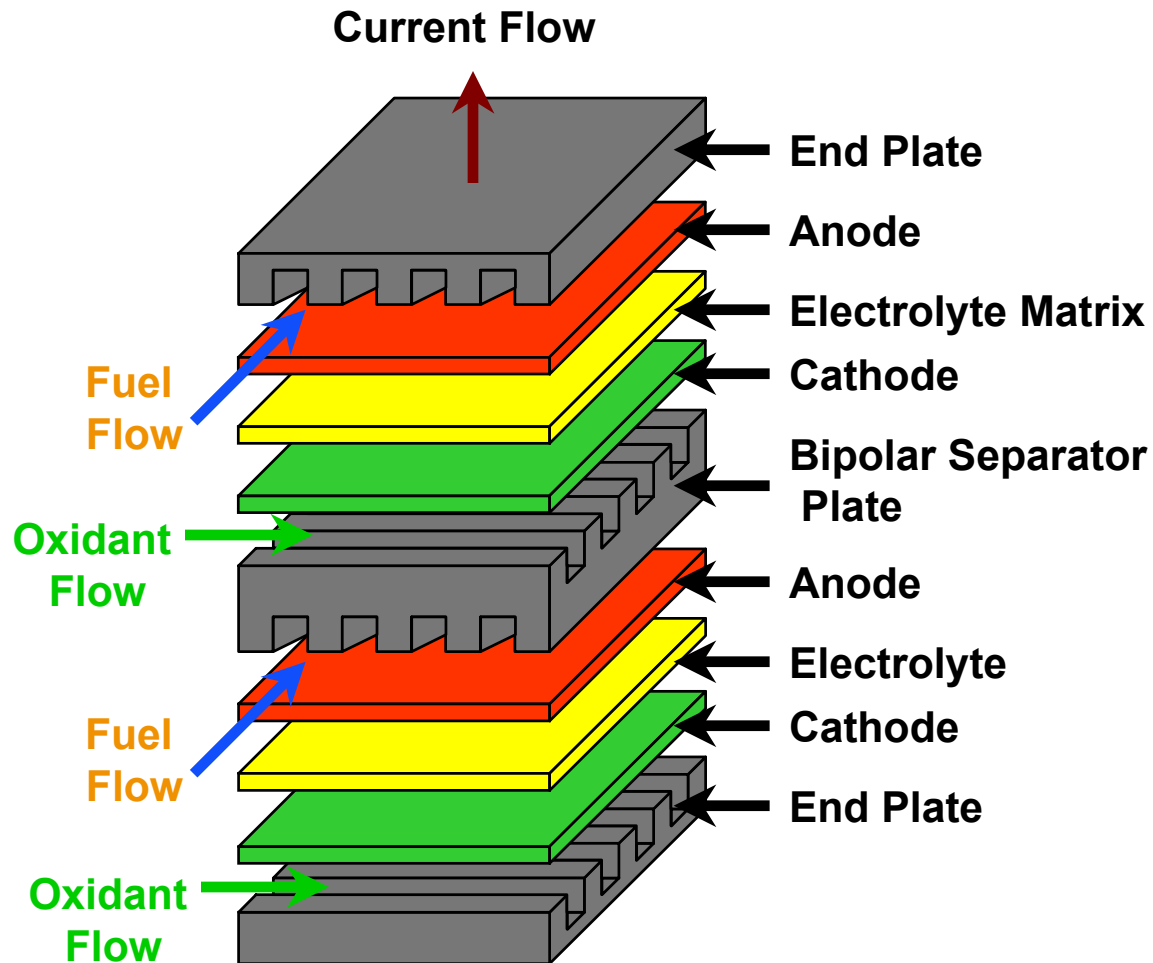
Solid State Fuel Cell



- Electrochemical process
- Direct conversion to electricity
- $\text{H}_2 + 1/2 \text{O}_2 \longrightarrow \text{H}_2\text{O} + \text{Electricity}$
- Continuous as long as fuel and air are provided



Planar Cell



Types of Fuel Cells

TYPE	TEMP	CHARGE CARRIER
• Solid Oxide	2000 F	O ⁻⁻
• Carbonate	1250 F	CO ₃ ⁻⁻
• Phosphoric Acid	400 F	H ⁺
• Polymer	160 F	H ⁺
• Alkaline	180 F	OH ⁻



Alkaline Fuel Cells

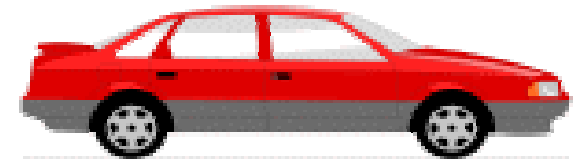
1970's

- Space - IFC
- Vehicle Prototypes - AC



2005

- Distributed Generation
- Vehicle



Phosphoric Acid Fuel Cells

1993

- “Commercially ready”



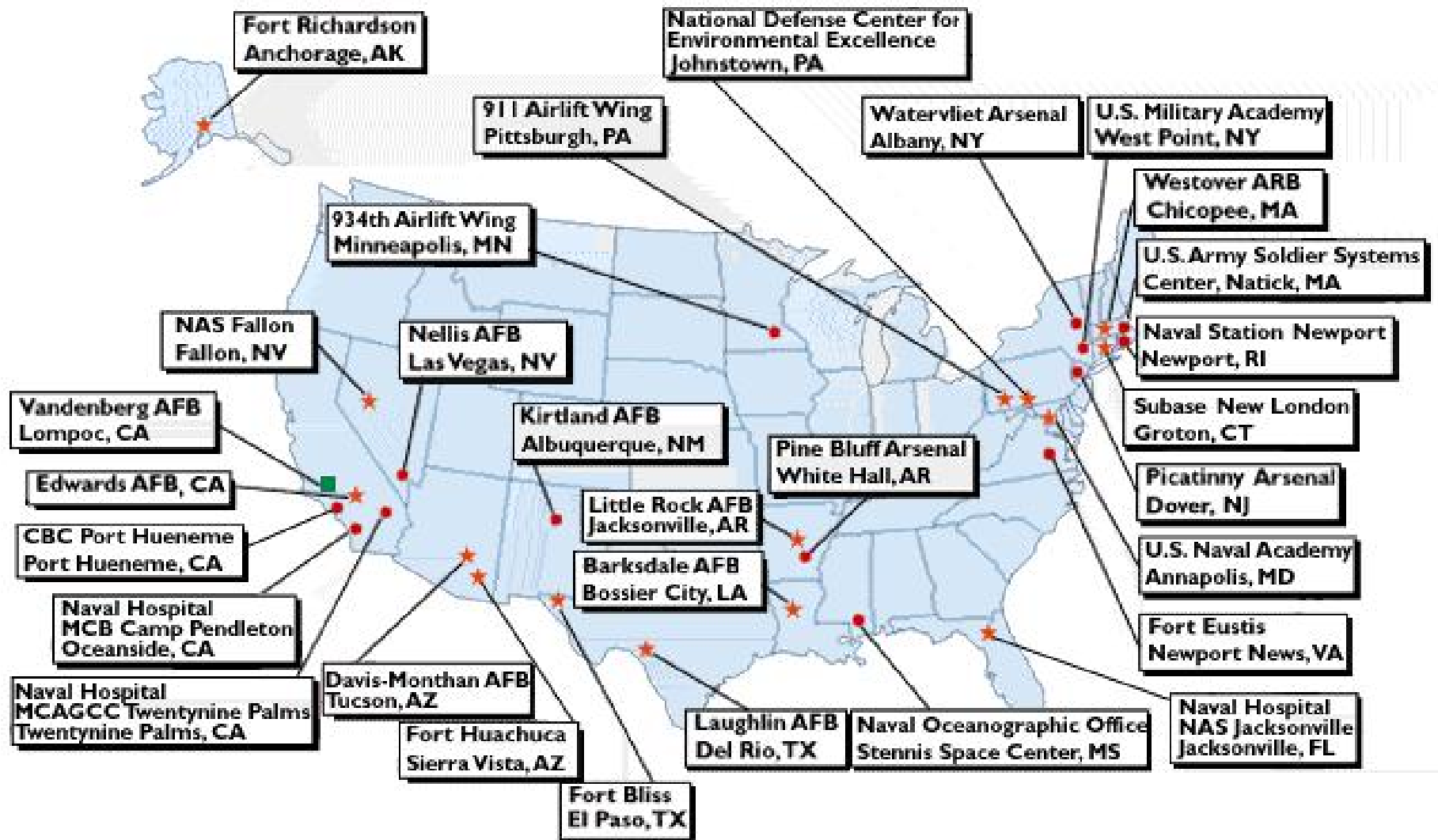
2002

- 220 200kW units
- >40% efficiency
- \$4,500/kW
- 95-98% availability
- 4 million customers
- 4 million hours
- 99.99-99.9999 reliability

*DoD cost-shared
in 3/4 of units*



US DOD PAFC Program



Diversity of Fuel Cell Technology and Unit Sizes: Accomplished by DoD

- **1996-97 Appropriations**

Rebates awarded for 53
ONSI (UTC-IFC) PC25 200
kW PAFC

- **1998 Appropriations**

15 ONSI PC25 200 kW
PAFC (1 Australia)
90 Plug Power 7 kW PEMFC
16 Analytic Power 3 kW
PEMFC
1 SWPC 300 kW SOFC

- **1999 Appropriations**

10 IdaTech 3 kW PEMFC
23 Plug Power 7 kW PEMFC
8 ONSI 200 kW PAFC
1 SWPC 250 kW SOFC
1 Fuel Cell Energy 250 kW
MCFC

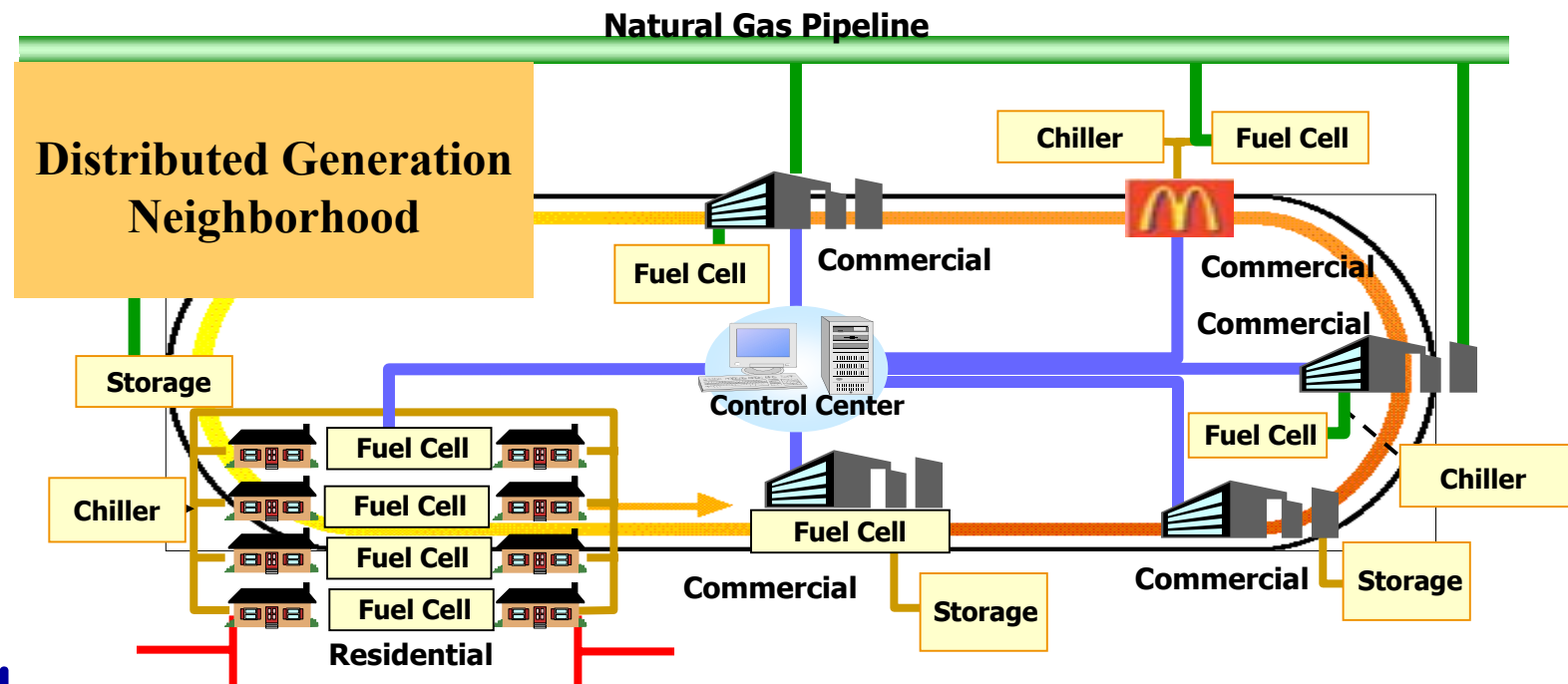
- **2000 Appropriations**

5 IFC 200 kW PAFC
3 Fuel Cell Energy 250 kW
MCFC
1 SWPC 250 kW SOFC
1 FCT 5 kW SOFC



Distributed Generation

- New paradigm
- Transforming technology
- Distribution companies may be the new transmission companies
- Least cost approach today in some areas



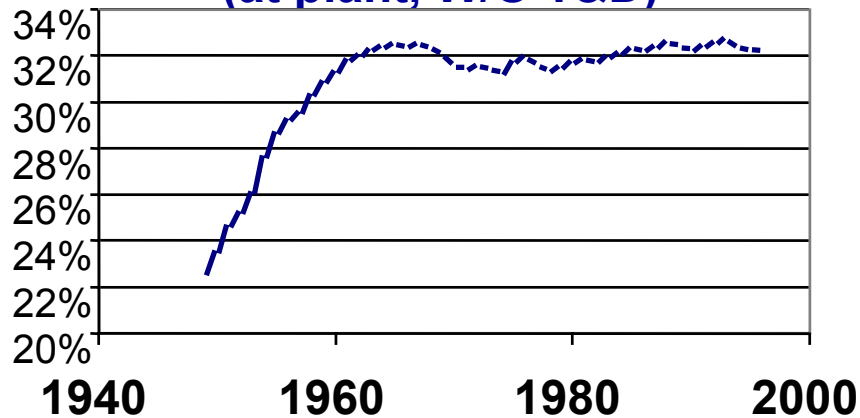
Benefits of Distributed Generation Systems

- **Environmentally clean power**
- **Enhanced reliability**
- **Improved efficiency**
- **Lower costs**
- **Power quality**
- **Design flexibility**
- **Fuel flexibility**
- **Transmission savings**



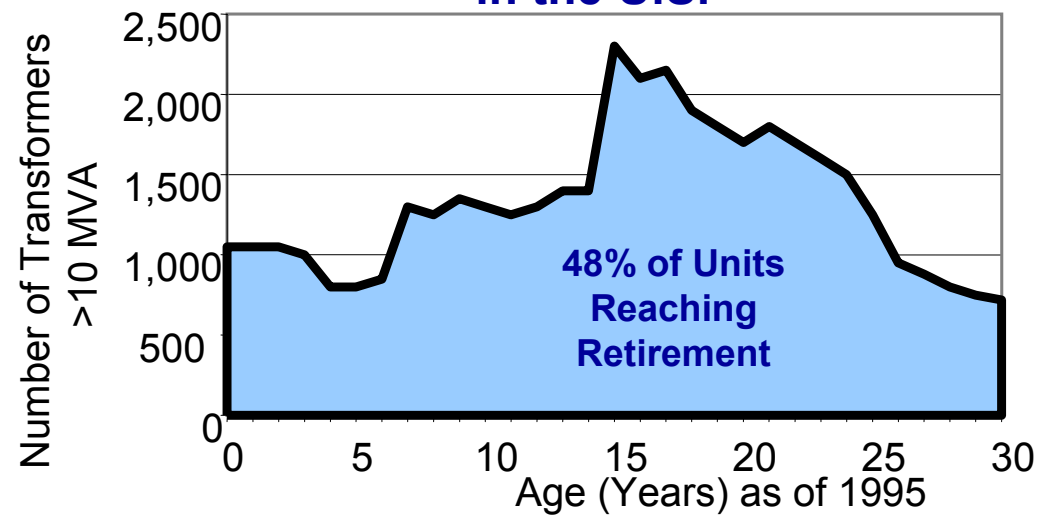
Aging Power Infrastructure

**Fossil Electric Generation Efficiency
(at plant, W/O T&D)**



Source: EIA, Annual Energy Review 1996

**Installed Transformer Banks
in the U.S.**



Source: Waukesha Electric Systems 1997



Distributed Generation Hurdles

- **Technical Standards**
 - Interconnection with electric power system
 - Electrical/Fire/Mechanical Safety
 - Data/Communications
 - Software
 - Architecture/Modularization/Physical connection
- **System Integration R&D**
 - Increase component integration
 - Develop cost-effective advanced plug-and-play interconnection and control technologies
 - Enhance capability to integrate, interact, and provide operational benefits
 - Enterprise energy management systems and resource planning
 - Grid support, ancillary services, and load/demand management
 - Adaptive, intelligent technology
- **Mitigation of Regulatory and Institutional Barriers**
 - Utility interconnection and related tariffs
 - Emissions regulations
 - Local siting and permitting



Near Term DG Market (Courtesy of FCE)

<u>US MARKET</u>	<u>2001</u>	<u>2002</u>	<u>2003</u>	<u>2004</u>	<u>2008</u>
INSTALLED CAPACITY (GW) -GROWTH RATE 1.3%, REPLACEMENT .7%	832	843	854	865	911
TOTAL GENERATION MARKET (GW)	16.6	16.9	17.1	17.3	18.2
DIST. GEN. MARKET (MW) -PERCENT TO TOTAL	2,662 16%	3,034 18%	3,415 20%	4,151 24%	6,738 37%
<u>EURO. MARKET</u>	<u>2001</u>	<u>2002</u>	<u>2003</u>	<u>2004</u>	<u>2008</u>
INSTALLED CAPACITY (GW) -GROWTH RATE 1.3%, REPLACEMENT 1.2%	790	800	810	821	865
TOTAL GENERATION MARKET (GW)	19.7	20.0	20.3	20.5	21.6
DIST. GEN. MARKET (MW) -PERCENT TO TOTAL	2,764 14%	3,000 15%	3,242 16%	3,489 17%	4,323 20%

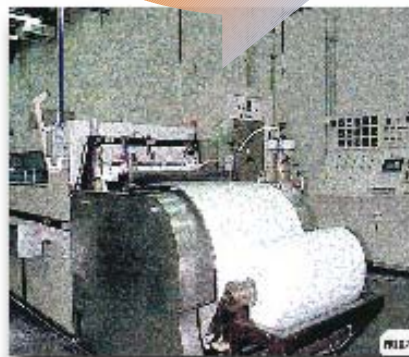


Molten Carbonate Fuel Cells



2002

- Demonstration
- 47% efficiency
- \$2,000/kW
- 250kW
- Internal reforming
- FCE Manufacturing 50MW/year



2003-2008

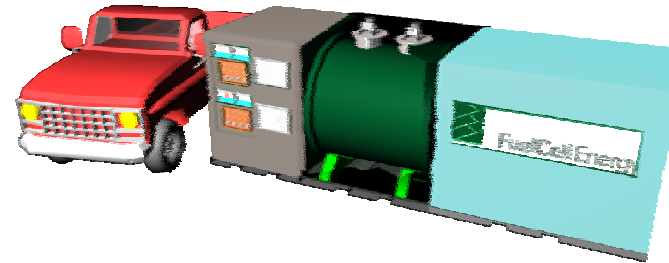
- Near-term DG market
- 54% efficiency
- \$1,000-1,500/kW
- 250kW-3MW



FCE Direct Fuel Cell Demonstrations

- **250-kw units**

- Bielefeld, Mercedes, LADWP, Thermie, Rhoen-Klinikum - 12, 250kW's
- Diesel Bath Maine - 500kW



- **1-MW units**

- King County Digester Gas



- **2-MW Units**

- Kentucky Clean Coal



Tubular Solid Oxide Fuel Cells



2002

- 47% efficiency
- > \$10,000/kW
- 100-220kW
- 16,000 operation at 100-kW

2003-2008

- Near-term DG market
- 47- 63% efficiency
- Homestead 15MW/yr Manufacturing facility 2003 (\$4500/kW)
- 250kW - 550kW



Fuel Cells Will Play a Role in Mitigating Climate Change

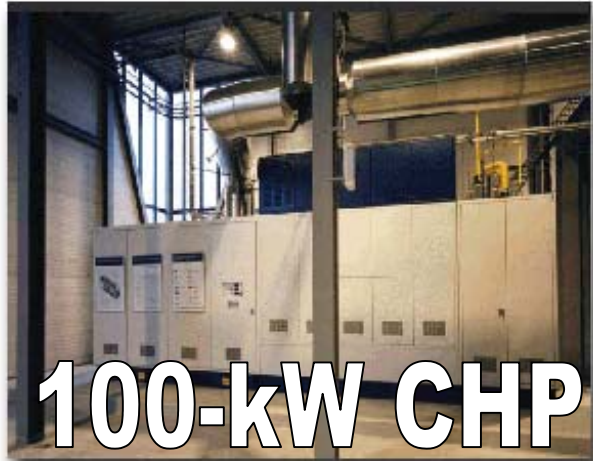
SWPC Tubular SOFC 100 kW_e CHP System



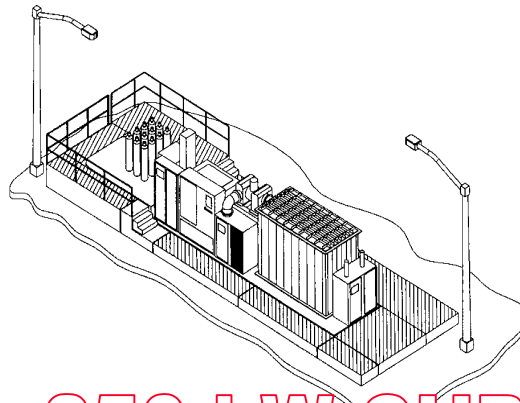
46% electrical efficiency
16,610 power generating hours
12,000 hours with no measureable power degradation
Emissions less than 1ppm NO_x, SO_x and CO and C_xH_y



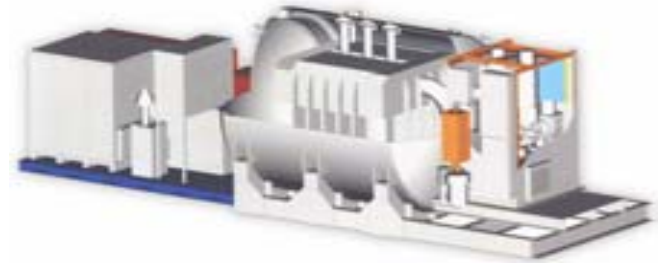
SWPC Demonstration Units



EDB/Elsam



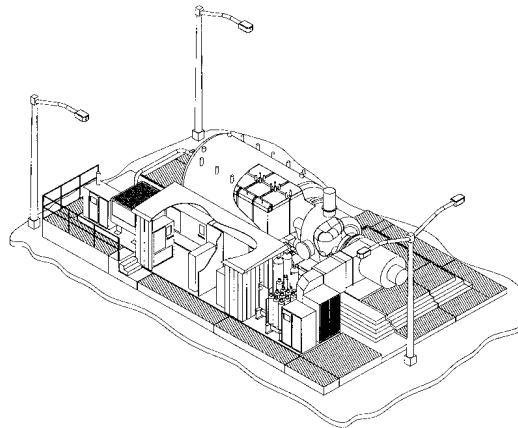
250-kW CHP



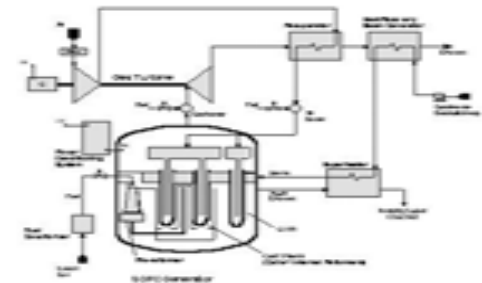
320-kW CC



NFCRC/Southern California Edison



1-MW CC



**150-kW
Carbon Sequestration**



PEM Fuel Cells



2002

- 24 - 32% efficiency
- > \$10,000/kW
- 1 to 250 kW
- Stationary and Transportation Initiatives

2004-2008

- Near-term DG, residential, APU, battery replacement
- 30-40% efficiency
- \$400 - 1,500/kW
- 50 W to 250 kW



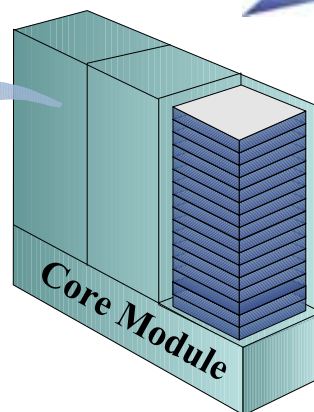
North American PEM Developers

- Ballard (Canada)
- Enable/DCH
- Avista
- General Motors
- Visteon
- IdaTech
- Schatz (Humboldt State)
- IGT/Mosaic
- Millenium
- Hydrogenics (Canada)
- Reliant (TAM)
- Nuvera
- IFC
- Dais-Analytic
- Energy Partners
- Plug Power
- H Power
- Honeywell
- Stuart (Canada)
- Gore
- Protonex



Solid State Energy Conversion Alliance (SECA) A Way To the Future

Transportation



Stationary



Military



Core Modules for Multiple Applications

Strategic Center for Natural Gas

G-162862 MCW 02/02

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Public Economic and Environmental Benefits

Economic

- **Nearly 80 GW/year total new/replacement electric generation global market by 2010**
 - 2% growth and replacement
 - \$32 billion/year at \$400/kW
- **Sales Residential - 25 million homes US & 50 million homes Europe**
 - \$150 billion at \$400/kW
- **Potential Truck 2 GW/year APU sales**
 - \$4 billion/year at \$400/kW
- **Ultimate Long-term Economic Impact**
 - 55 million vehicles/year global transportation market
 - \$200 billion/year at \$50/kW

Environmental

- **Lower emissions**
 - 60% efficient fuel cell hybrid systems cut CO₂ by 1/2
 - Fuel cells virtually eliminate NOx in stationary and transportation applications



Annual U.S. Emissions Saved Using APUs in Class 8 Trucks



- **Diesel fuel saved: 419 million gal/yr**
- **CO₂ reduced: 4.64 million tons/yr**
- **Assumes:**
 - 2.1 million Class 8 trucks
 - 311,000 have overnight routes (APU candidates)



SECA Development: Progressive Applications



2005

- \$800/kW
- Prototypes (β -Units)
3 - 10 kW
- Delphi,
Cummins/McDermott,
Honeywell, SWPC

2010

- \$400/kW
- Commercial



2015

- Vision 21 Power Plants
70-80% efficient plants
- Propulsion <\$200?/kW



Automotive Auxiliary Power Unit



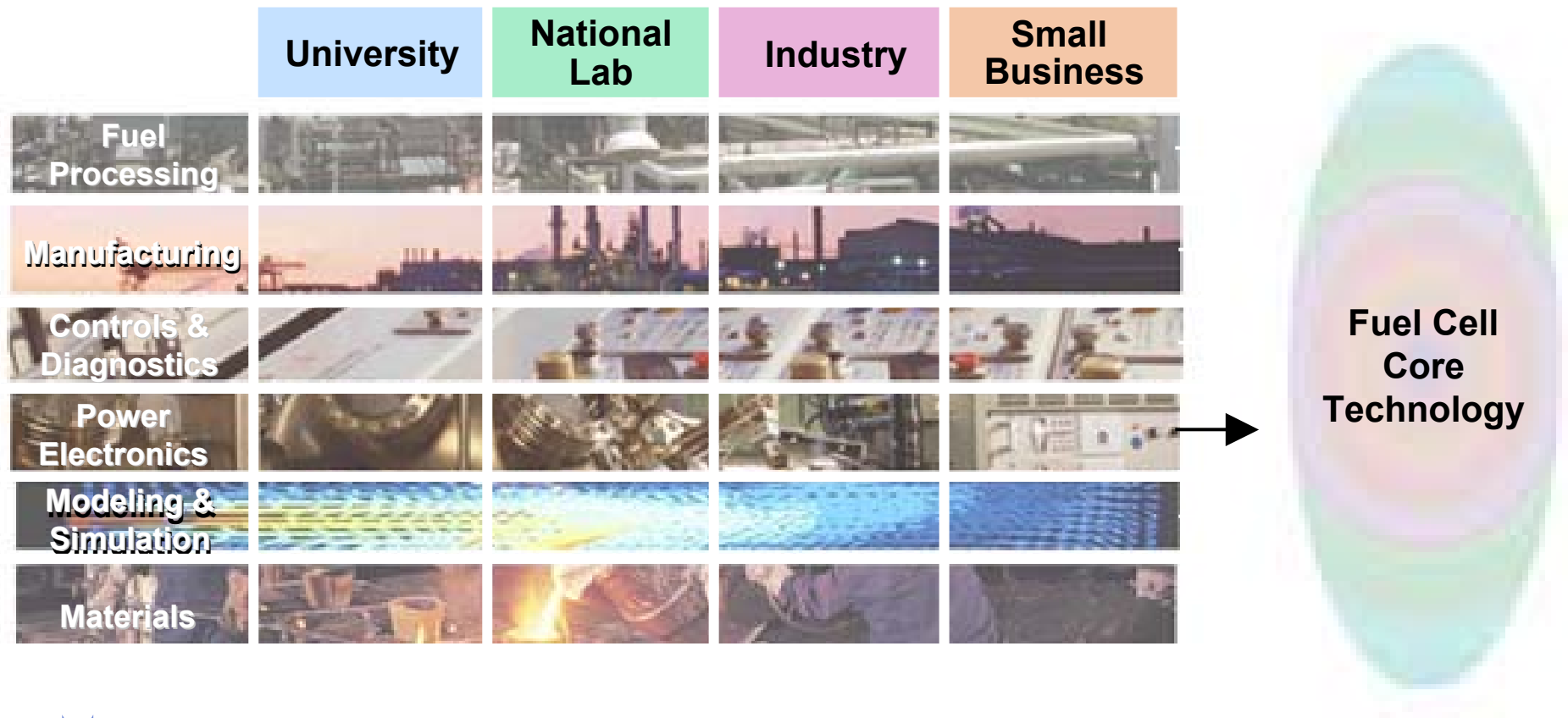
DELPHI

Automotive Systems



Core Technology Program

The Technology Base



North American SOFC Players

- 
- Global Thermoelectric (Canadian)
 - FCT (Canadian)
 - IFC
 - Ceramtec
 - IGT
 - Zetek
 - Accumetrics
 - MSRI
 - American Fuel Cell
 - **SWPC (German/US)**
 - **Delphi**
 - **NexTech**
 - **Honeywell**
 - **McDermott/Cummins**
 - **TMI**
 - **PNNL, NETL, ANL, ORNL, LANL, LBL, LLNL**
 - **Universities**



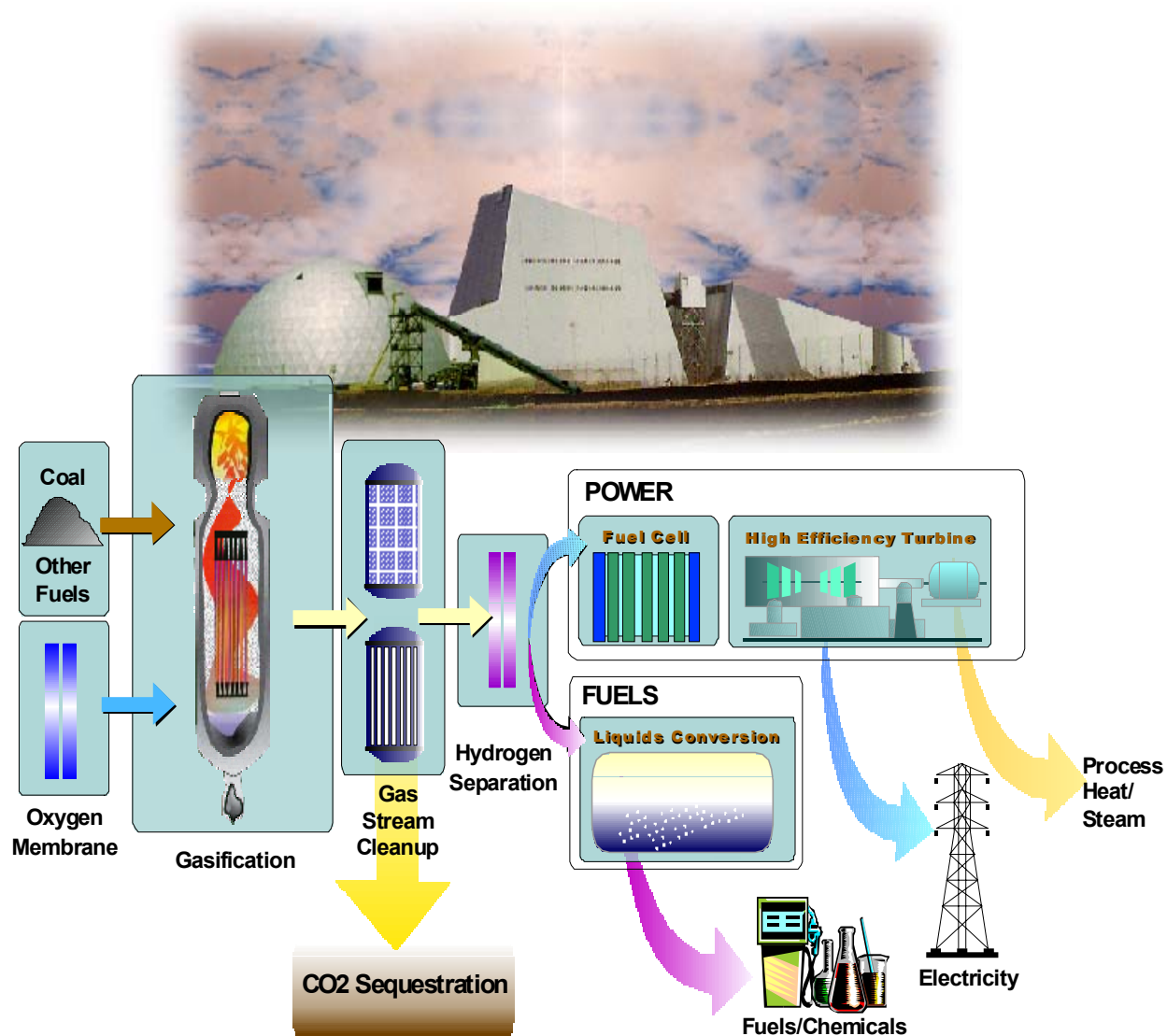
(Note: **SECA-funded in red**)

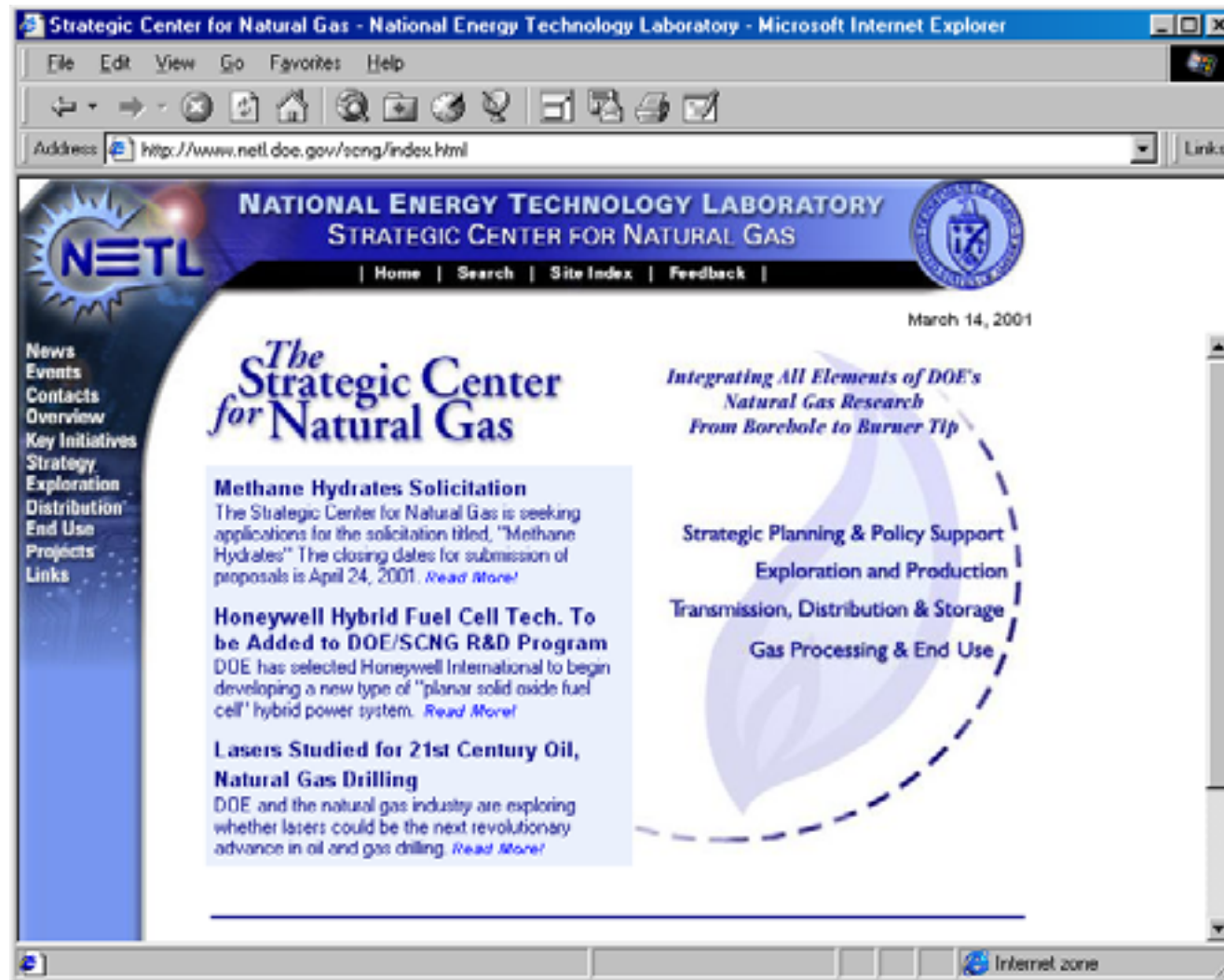
Definition of Hybrid Fuel Cell

- A combined cycle power generation system containing a high-temperature fuel cell plus a:
 - ✓ Gas turbine *or* other heat engine
 - or*
 - ✓ Another fuel cell



Vision 21 Hybrids

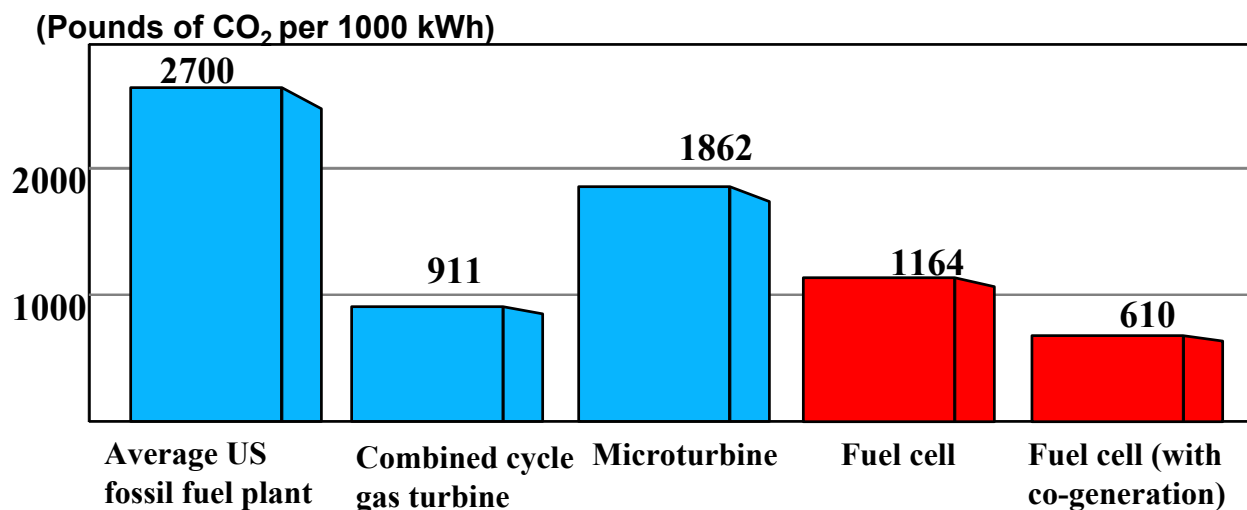
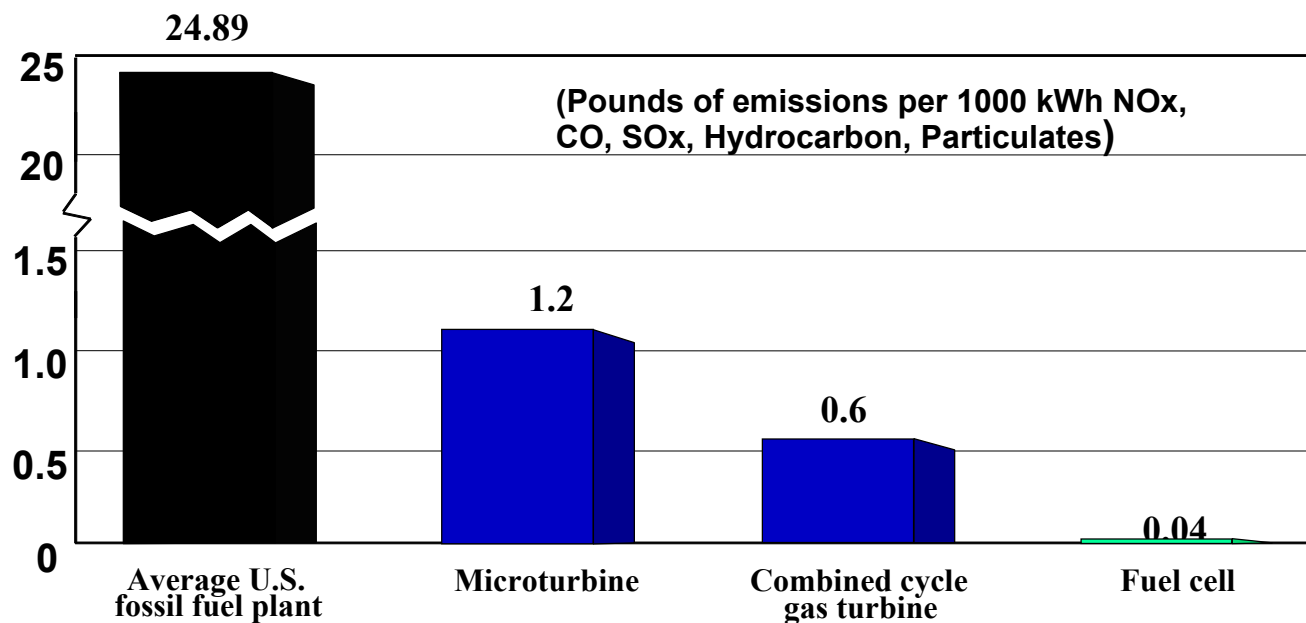




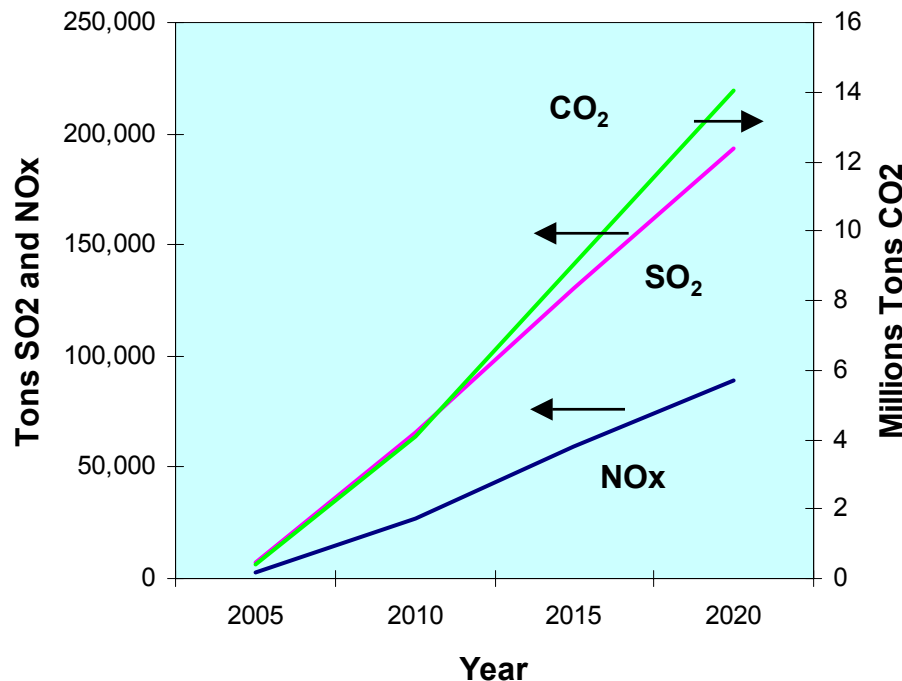
mark.williams@netl.doe.gov



Fuel Cell Emissions and Efficiency



Annual U.S. Emissions Saved Using Fuel Cells for Power Generation



Assumptions:

AEO 2002 capacity addition projections

SOFC/MCFC efficiencies & emissions

75% capacity factor for fuel cells

Year	Additions (Total)	Fuel Cells %	GW
2005	68 GW	1%	0.7
2010	185 GW	2%	3.7
2015	267 GW	4%	10.7
2020	254.5 GW	5%	12.7

- By 2020:**

EERE Program goal is 20 GW/yr of D.G.

EPRI claims 20% of additions go to D.G.

